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Measurement of $dN/d\eta$ and $dE_T/d\eta$ in PbPb collisions with CMS

Michael Murray

University of Kansas for the CMS collaboration

Abstract

The charged particle multiplicity and transverse energy in PbPb collisions at 2.76 TeV nucleon-nucleon center-of-mass energy ($\sqrt{s_{\mathrm{NN}}}$) has been measured over a broad range of pseudorapidity (η) and collision centrality using the CMS detector at the LHC. The transverse energy density per unit pseudorapidity ($dE_T/d\eta$) increases faster with collision energy than the charged particle multiplicity $dN/d\eta$. This implies that the mean energy per particle is increasing with collision energy. At all pseudorapidities the multiplicity and transverse energy per participating nucleon increases with the centrality of the collision. The ratio of transverse energy per unit pseudorapidity in peripheral to central collisions varies significantly as the pseudorapidity increases from $\eta = 0$ to $|\eta| = 5.0$.

The Compact Muon Solenoid (CMS) experiment is a general-purpose detector designed to study hadron collisions at the TeV scale [1]. In particular, it has almost hermetic calorimetry that is sensitive to the distribution of energy over nearly the complete angular range. This facilitates a good estimate of the total transverse energy produced in the event and the measurement of the width of its pseudorapidity distribution. The transverse energy is defined by $E_T = \sum_i E_i \sin\theta_i$, where E_i is the energy seen by the calorimeter for the i^{th} particle, θ_i is the polar angle of particle i, and the sum is over all particles emitted into the $d\eta$ region in an event. The transverse energy is studied as a function of the geometry of the collision, i.e. the centrality, of the heavy-ion interaction. Finally, comparisons are made with lower energy data and theoretical models.

The central feature of the CMS apparatus is a superconducting solenoid, of 6m internal diameter, providing a magnetic field of 3.8 T. Within the central field volume are the silicon pixel and strip trackers, lead-tungstate crystal electromagnetic calorimeter and the brass-scintillator hadron calorimeter. These calorimeters are physically divided into the barrel and endcap regions covering together the region of $|\eta| < 3.0$. The hadronic forward (HF) calorimeters cover $|\eta|$ from 2.9 to 5.2. The HF calorimeters use quartz fibers embedded within a steel absorber. The muon system is located outside the magnet and covers the region $|\eta| < 2.2$ The CMS tracking system, located inside the calorimeter, consists of pixel and silicon-strip layers covering $|\eta| < 2.5$. A set of scintillator tiles, are mounted on the inner side of the HF calorimeters to trigger on heavy-ion collisions and reject beam-halo interactions.

Figure 1 shows the η dependence of the multiplicity and transverse energy density for various ranges of centrality. In the range $|\eta| < 2$ there is little change in either dN/η or $dE_T/d\eta$. For the most central collisions $dE_T/d\eta$ exceeds 2 TeV at $\eta = 0$. This is much larger than the value of 0.61 TeV measured at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV [2]. At lower center-of-mass energies the pion multiplicity distributions are reasonably well described by Gaussians in rapidity with widths that are consistent with Landau-Carruthers hydrodynamics [3, 4]. Since the mean p_T of all particle species depends only weakly on rapidity, this implies that $dE_T/d\eta$ is roughly Gaussian in rapidity at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. Recently,

Email address: mjmurray@ku.edu (Michael Murray)

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Wong has improved the formulation of Landau hydrodynamics [5] to give a better description of the RHIC data. The transverse energy distribution is consistent with a Gaussian (black solid line) with $\sigma_\eta = 3.6 \pm 0.1$ for the most central collisions. The Gaussian and Landau curves in Fig. 1 are normalized to the CMS data at $\eta = 0$. Both the Landau-Carruthers (blue dashed), and Landau-Wong (green dotted) formulations have distributions that are narrower than the data. Therefore the longitudinal expansion of the system is stronger than that predicted from either model. The HYDJET 1.8 model, shown by the purple dashed line, has been tuned to LHC data in the small $|\eta|$ region. For central collisions it gives a good description of $dE_T/d\eta$ at small $|\eta|$ but overestimates the data at large $|\eta|$. The AMPT (A Multi Phase Transport) model [6, 7] (orange dashed line) overestimates transverse energy production for central collisions but is in rough agreement with the shape of the distribution in $|\eta|$.

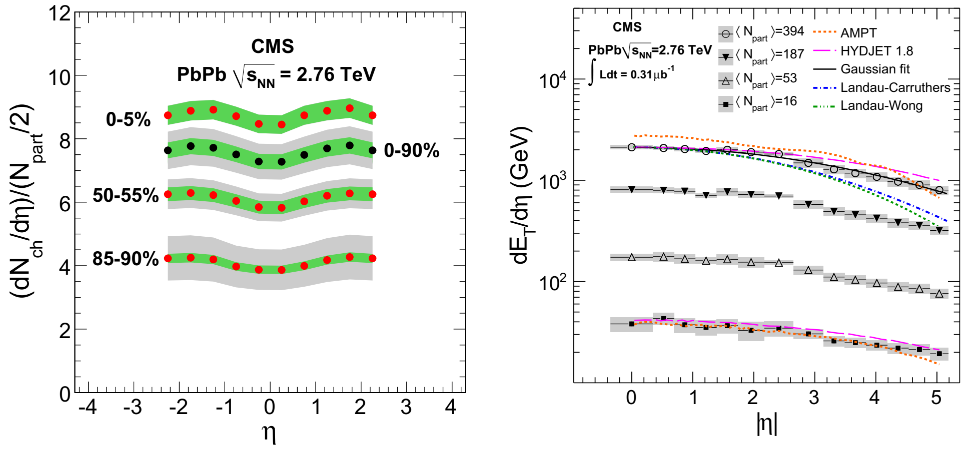

Figure 1: $dN/d\eta/(\langle N_{\text{part}}\rangle/2)$ (left) and $dE_T/d\eta$ (right) for a range of centralities. The bands and boxes show the total systematic uncertainties. The statistical uncertainties are negligible. Also shown for $dE_T/d\eta$ are a Gaussian fit and the predictions of various models (see text).

Figure 2 shows the evolution of the multiplicity and transverse energy with $\langle N_{\text{part}}\rangle$. Both $(dN/\eta)/(\langle N_{\text{part}}\rangle/2)$ $(dE_T/\eta)/(\langle N_{\text{part}}\rangle/2)$ have a similar shape, i.e. a rapid rise at low N_{part} followed by a leveling off and then a hint of an upturn for the most central events. The $\langle N_{\text{part}}\rangle$ dependence of transverse energy density changes as a function of pseudorapidity. This effect can be quantified by comparing peripheral (60–70)% ($\langle N_{\text{part}}\rangle = 30$) to central (0–2.5)% collisions ($\langle N_{\text{part}}\rangle = 394$) at various pseudorapidities. The ratio of peripheral to central $(dE_T/d\eta)/(\langle N_{\text{part}}\rangle/2)$ changes from $54 \pm 2\%$ at $\eta = 0$ to $68 \pm 2\%$ at $|\eta| = 5.0$. The PHENIX collaboration at RHIC has studied transverse energy density in AuAu collisions for $|\eta| < 0.35$ over a wide range of centralities and for $\sqrt{s_{\text{NN}}}$ from 19.6 to 200 GeV [2]. At $\sqrt{s_{\text{NN}}} = 19.6$ GeV $(dE_T/dE_\eta)/(\langle N_{\text{part}}\rangle/2)$ at $\eta = 0$ increases by a factor of 1.25 ± 0.17 as $\langle N_{\text{part}}\rangle$ increases from 63.8 to 336. At $\sqrt{s_{\text{NN}}}$ =2.76 TeV this factor is found to be 1.47 ± 0.13 for a similar range of $\langle N_{\text{part}}\rangle$. The model of Albacete & Dumitru gives a good description of the multiplicity data [8]. For E_T, the HYDJET 1.8 code gives a good description of the centrality dependence of $dE_T/d\eta$ at $\eta = 0$.

Figure 3 shows the energy dependence of both transverse energy and multiplicity normalized by $N_{\text{part}}\rangle/2$. For energies above about 8 GeV both rise as a power law in $\sqrt{s_{\text{NN}}}$ but E_T rises faster. This implies that the transverse energy per charged particle increase with beam energy and suggests that temperature of the matter created in heavy ion collisions increases with $\sqrt{s_{\text{NN}}}$.

To summarize, both multiplicity and transverse energy have similar dependences on η, N_{part} and beam energy. Both $(dN/\eta)/(\langle N_{\text{part}}\rangle/2)$ and $(dE_T/\eta)/(\langle N_{\text{part}}\rangle/2)$ show little variation with η for $\eta \leq 2$. The number of charged particles and the transverse energy increase rapidly with the number of participants in the collision and for $\eta = 0$, $(dN/\eta)/(\langle N_{\text{part}}\rangle/2)$ and $(dE_T/\eta)/(\langle N_{\text{part}}\rangle/2)$ have a similar evolution with N_{part}. For beam energies between 8

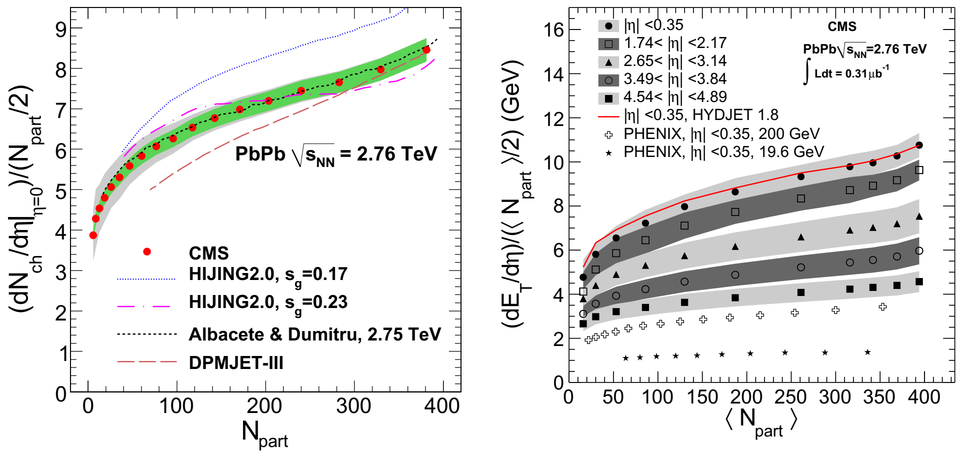

Figure 2: Multiplicity (left) and transverse energy density (right) normalized by $(\langle N_{\rm part}\rangle/2)$ versus $\langle N_{\rm part}\rangle$ for PbPb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV at several values of $|\eta|$. The bands show the total systematic uncertainties. The statistical uncertainties are negligible. Predictions from various models are also shown. The right hand panel also shows lower energy E_T data from the PHENIX collaboraiton

and 2760 GeV $(dN/\eta)/(\langle N_{\rm part}\rangle/2)$ and $(dE_T/\eta)/(\langle N_{\rm part}\rangle/2)$ increase as a power law of $s_{\rm NN}$ although E_T rises faster. The very large angular coverage of the CMS calorimeters allows us to study E_T production out to $\eta = 5$. The $(dE_T/\eta)/(\langle N_{\rm part}\rangle/2)$ data are consistent with a Gaussian form but with widths that are wider than those predicted by Landau Hydrodynamics. The shape of $(dE_T/\eta)/(\langle N_{\rm part}\rangle/2)$ versus $N_{\rm part}$ depends upon η, becoming flatter towards $\eta = 5$.

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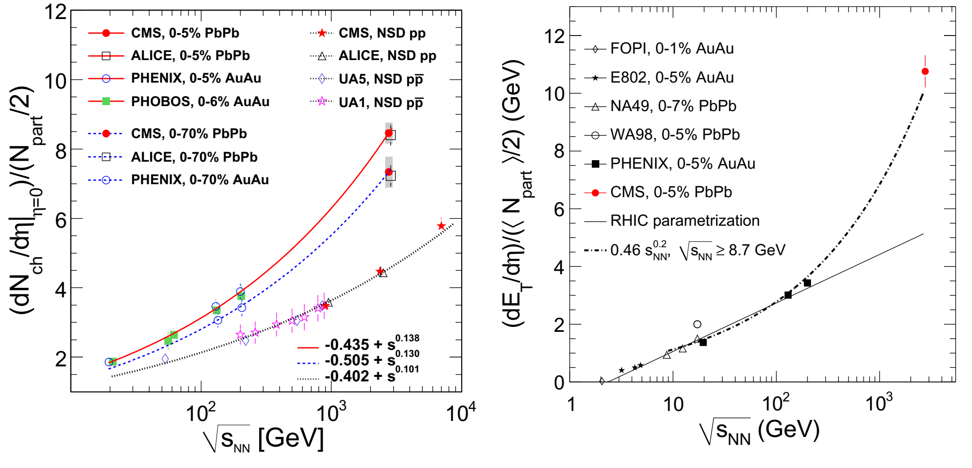

Figure 3: Charged particle multiplicity (left) and transverse energy density (left) and normalized by $(\langle N_{\rm part}\rangle/2)$ for central collisions at $\eta = 0$ as a function of the center-of-mass energy. The vertical bars on the CMS points are the full systematic uncertainty. The statistical uncertainties are negligible. The solid line in the right hand panel is a parameterization used at RHIC [2]. The lower-energy data are from [2, 9, 10, 11, 12, 13, 14, 15, 16]. The dashed line corresponds to a power law fit $s_{\rm NN}^{n}$ for $\sqrt{s_{\rm NN}} \geq 8.7$ GeV.